Photon Interaction of WO_3:BaO:ZnO:B_2O_3 glasses in energy range 1 keV − 10^5 keV:Theoretical Calculation

Wiraporn Hongtong [a, b], Jakrapong Kaewkhao [a, b], Pruittipol Limkitjaroenporn[a, b, *]

[a]*Center of Excellence in Glass Technology and Materials Science (CEGM), Nakhon Pathom Rajabhat University,Nakhon Pathom, 73000, Thailand*
[b]*Physics Program, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom, 73000, Thailand*

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Abstract

The photon interaction, mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}) and effective electron density (N_e) of WO_3: BaO:ZnO:B_2O_3 glasses have been calculated by using the WinXCom program in energy range from 1 − 10^5 keV. The results shown the total and partial interactions varied with the concentration of additive WO_3. At low photon energy found that the photoelectric absorption is the main interaction in the energy range 1 − 10^3 keV, the values were decreased with increasing of photon energy. The values found the raised suddenly near the M-, L- and K- absorption edge of WO_3 and show the higher raised when increase WO_3 concentration. The coherent scattering has been found in energy range 1 − 10^2 keV and the values decreased with increasing of photon energy and increased with increasing of WO_3 concentration. The incoherent scattering is the main photon interaction process in energy range 10^1 − 10^3 keV, the values were increased with increasing in photon energy range 1 − 10^2 keV and decreased in photon energy range 10^2 − 10^5 keV and all the trend were increased with increasing of WO_3 concentration. The pair production in nuclear field occurs at photon 1.02 × 10^3 keV and it increases with increase in photon energy. The mass attenuation shows the peak at low energy regions which corresponding to the photoelectric absorption edge, the values show the increase with increasing WO_3 concentration. The results of μ_m and the N_e have peak are corresponding to the M-, L- and K- absorption edge of tungsten and show the stronger peak when increases the concentration of WO_3. These results found to the same trend with the trend of the mass attenuation.

KEYWORDS: WO_3; mass attenuation coefficient; photon interaction; WinXCom; glass
*Corresponding authors ; E-mail: golfpo@hotmail.com

Introduction

Radiation fields such as physics, medical diagnostic, radiation protection, nuclear medicine, the parameter indicated efficiency of material for radiation shielding namely the total mass attenuation coefficient (μ_m) the effective atomic numbers (Z_{eff}) and the effective electron densities (N_e) required in the determining the of X-ray and gamma-ray various researchers have been studied on different materials [1].

Glass is one of the materials that can be used for radiation shielding materials, the advantages of glass are good homogeneity and excellent transparency [2]. The glasses containing heavy metal ions or transition metal ions exhibit shielding behavior towards successive gamma irradiations [3]. Tungsten oxide (WO_3) is transition metal oxide, has density is 7.16 g cm^{-3}. WO_3 cannot form glasses by themselves, but chemical composition in combination with other glass formers like B_2O_3 and has the ability to make great glass-forming regions with high concentration [4 − 5]. Barium oxide (BaO) are playing on important role in radiation glass shielding and replacing lead due to environmental hazardous of lead and protectionism in world economy. In literature reviews on radiation shielding glass development have been published recently by several authors [6]. Zinc oxide (ZnO) is lower melting point the formation of oxide glasses [7].

Previous work, there are many researchers studied the radiation shielding properties for glasses using WinXCom program [8], such as in 2010 J. Kaewkhao, P. Limsuwan [9] studied the mass attenuation coefficients (μ_m), partial interactions and the effective atomic numbers of

Bi_2O_3, PbO and BaO in glass have been investigated on the basis of the mixture rule at 662 keV. It has been found that the total mass attenuation coefficients of glasses increase with increasing Bi_2O_3 and PbO concentrations, due to the increasing photoelectric absorption in glass samples. The Z_{eff} increases with increase in Bi_2O_3, PbO and BaO concentrations, in 2016 M.I. Sayyed [10] present the gamma ray shielding properties of tellurium oxide based quaternary glasses in the system TeO_2:B_2O_3:Bi_2O_3:ZnO have been investigated. By using WinXCom, The values of μ_m, the Z_{eff} found increase with an increasing in Bi_2O_3 content and in 2017 M.G. Dong and et al. [11] studied in topic shielding properties of $80TeO_2$:$5TiO_2$: (15 − x) WO_3:xAnOm glasses using WinXCom in the photon energy range of 100 − 80 keV, the results found that photoelectric effect and pair production appearing at lower and higher energy regions, the mass attenuation coefficients decreases quickly in the low energy region and almost becomes constant in the high energy region.

In this work, the WO_3:BaO:ZnO:B_2O_3 glasses in composition xWO_3:20BaO:20ZnO:(60 − x) B_2O_3 (where x = 0, 5, 10, 15, 20 and 25 mol%) have been studied the photon interaction in the energy range 1 − 10^5 keV by using WinXCom program.

Materials and Methods

The chemical compositions (weight fraction) of the WO_3:BaO:ZnO:B_2O_3 glasses shown in Table 1. The theoretical values of the mass attenuation coefficients, (μ_m) of compound have been calculated by WinXCom, based on mixture rule [9] as show in equation (1);

$$\mu_m = \sum_i^n w_i (\mu_m)_i \quad (1)$$

Where W_i is weight fraction of each element in mixture, $(\mu_m)_i$ is mass attenuation coefficient for individual element in mixture. The theoretical values for the mass attenuation coefficient can be found in the tabulation by Hubbell and Seltzer.

A lot of manual work can be saved by using suitable software. Berger and Hubbell developed XCOM for calculating mass attenuation coefficients or photon interaction cross-sections for any element, compound or mixture of energy from 1 keV to 100 GeV. Recently, XCOM was transformed to the windows platform by Gerward et al. [12], called WinXCom.

WinXCom can generate cross-section or attenuation coefficients of element, mixture, and compound on a standard energy grid, spaced approximately logarithmically, on a grid specified by the user, or for a mix of both grids. The program provides total cross-sections and attenuation coefficients as well as partial cross-section for incoherent and coherent scattering, photoelectric absorption, and pair production. For compound, the quantities calculated are partial and total mass attenuation coefficients. Total attenuation coefficients without the contribution from coherent scattering are also given, since they are often used in gamma rays transport calculation [13].

The value of mass attenuation coefficients can be used to determine the total atomic cross-section ($\sigma_{t,a}$) by the following relation [9] as show in equation (2);

$$\sigma_{t,a} = \frac{(\mu_m)}{N_A \sum_i^n (w_i / A_i)} \quad (2)$$

Where N_A is Avogadro's number and A_i is atomic weight of constituent element of compound. The total electronic cross-section ($\sigma_{t,el}$) for the element is also expressed by the following formula. Where N_A is Avogadro's number and A_i is atomic weight of constituent element compound. The total electronic cross-section for the element is also expressed by the following formula [9] as show in equation (3);

$$\sigma_{t,el} = \frac{1}{N_A} \sum\nolimits_i^n \frac{f_i A_i}{Z_i} (\mu_m)_i \quad (3)$$

Where f_i is the number of atoms of element *i*

Table 1 Shows weight fraction of WO_3:BaO:ZnO:B_2O_3 glasses.

Mol % of WO_3	% weight fraction			
	WO_3	BaO	ZnO	B_2O_3
0	0.0000	0.3457	0.1835	0.4709
5	0.1197	0.3167	0.1681	0.3955
10	0.2209	0.2922	0.1551	0.3317
15	0.3076	0.2713	0.1440	0.2771
20	0.3827	0.2531	0.1343	0.2298
25	0.4484	0.2372	0.1259	0.1885

relative to the total number of atoms of all elements in compound and Z_i is the atomic number of the element in compound. Total atomic cross-section and total electronic cross-section are related to effective atomic number (Z_{eff}) of the compound through the formula [14] as show in equation (4);

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \quad (4)$$

The effective electron density (N_{el}) can be defined as the number of electrons per unit mass, and it can be mathematically written as follows [8] as show in equation (5);

$$N_{el} = \frac{\mu_m}{\sigma_{t,el}} \quad (5)$$

Results and Discussion

In this work, the WO_3:BaO:ZnO:B_2O_3 glasses in composition xWO_3:20BaO :20ZnO:(60 − x) B_2O_3 (where x = 0, 5, 10, 15, 20 and 25 mol%) have been studied the photon interaction in the energy range 1 − 10^5 keV by using WinXCom program. Fig. 1. shown that the photoelectric absorption was the main interaction at low photon energy (1 − 10^3 keV), the values were decreased with increasing of photon energy. The photoelectric absorption value found to be the raised suddenly around the K absorption edge of barium (37.44 keV) and tungsten (69.53 keV), the M absorption edge of barium (M3 1.06 keV, M2 1.14 keV and M1 1.29 keV) and tungsten (M5 1.81 keV, M4 1.87 keV, M3 2.28 keV, M2 2.58 keV and M1 2.82 keV) , the L absorption edge of barium (L3 5.25 keV, L2 5.62 keV and L1 5.99 keV) and tungsten (L3 10.21 keV, L2 11.54 keV and L1 12.10 keV). When the tungsten oxide adds into glass matrix, these absorption edges show the stronger peaks at the higher concentration of tungsten and this figure the blank peak occur peak of barium only due to WO_3 are not doped in glass matrix.

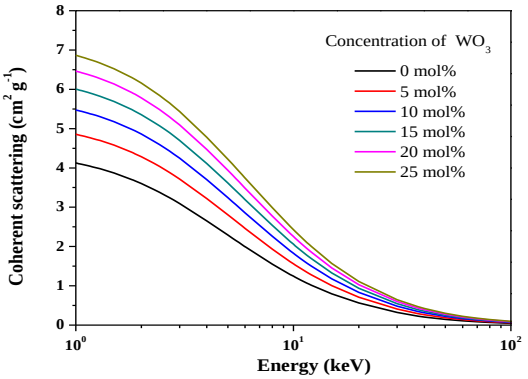

Fig. 2 The coherent scattering of WO_3:BaO:ZnO:B_2O_3 glasses.

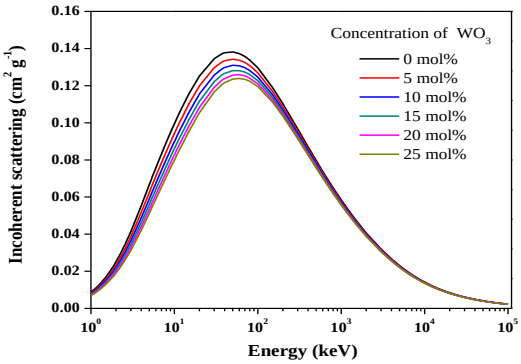

Fig. 3 The incoherent scattering of WO_3:BaO:ZnO:B_2O_3 glasses.

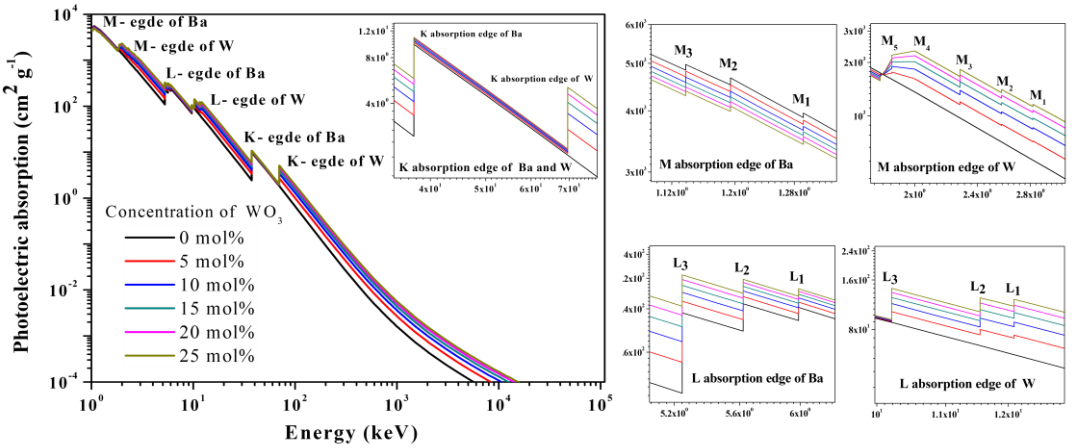

Fig. 1 The photoelectric absorption of WO_3:BaO:ZnO:B_2O_3 glasses.

The coherent scattering has been found at low energy ($1 - 10^2$ keV) and the values decreased with increasing of photon energy and increased with increasing of WO_3 concentration, the results shown in Fig. 2. Incoherent scattering shown in Fig. 3, these values were increased with increasing in photon energy range $1 - 10^2$ keV and decreased in photon energy range $10^2 - 10^5$ keV and show the increasing trend with increasing of WO_3 concentration. Moreover, the incoherent scattering found to be the main interaction at energy around $10^1 - 10^3$ keV.

The pair production in nuclear field occurs at photon 1.022×10^3 keV which corresponding to the total rest mass energy of electron (511 keV) and positron (511 keV), and it increases with increase in photon energy beyond 1.022×10^3 keV and show the higher interactions at higher concentration of WO_3. It found to be the main interaction at photon energy higher 2×10^4 keV as shows in Fig. 4.

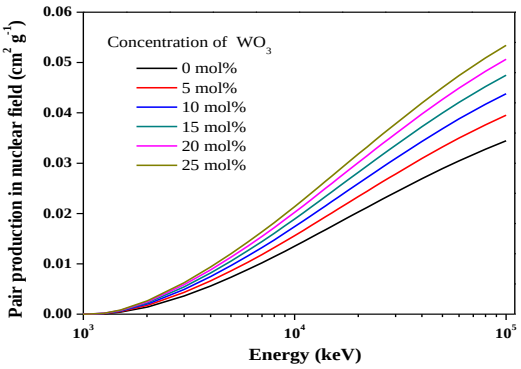

Fig. 4 The pair production in nuclear field of WO_3:BaO:ZnO:B_2O_3 glasses.

The mass attenuation coefficients were calculated by WinXCom program and the results shown in Fig. 5, which indicates the total interactions in energy range $1 - 10^5$ keV. The results shown that, the mass attenuation coefficients show the peak at low energy regions which corresponding to the photoelectric absorption edge. The results reflected to the photoelectric effect is the main interaction at the low energy range. The mass attenuation coefficients values increase with increasing WO_3 concentration in the energy range $1 - 10^5$ keV reflected to the higher to the probability interaction at higher concentration of WO_3 in this energy range. The blank peak of glass system occur peak of barium only due to WO_3 are not doped in glass matrix.

Fig. 6 shown the effective atomic numbers results which determined using Equation (4). The peak of effective atomic numbers has been appearing when the WO_3 added into this glass matrix. These peaks are corresponding to the M L- and K absorption edge of tungsten and show the strong peak when increases the concentration of WO_3. The results found to be that the same trend with the trend of the mass attenuation and show the interaction probability are strongly depended on the effective atomic numbers. The blank peak not found absorption edge of WO_3 and occur peak barium only due to WO_3 are not doped in glass matrix.

The effective electron densities have been determined from Equation (5) and the results show in Fig. 7. The results of the effective electron densities show the same trend of increase with increasing the WO_3 concentration reflection the electrons have been more created when the photon passing through at the higher WO_3 concentration. Moreover, the effective electron densities found to be the same trend of the effective atomic numbers. The blank peak

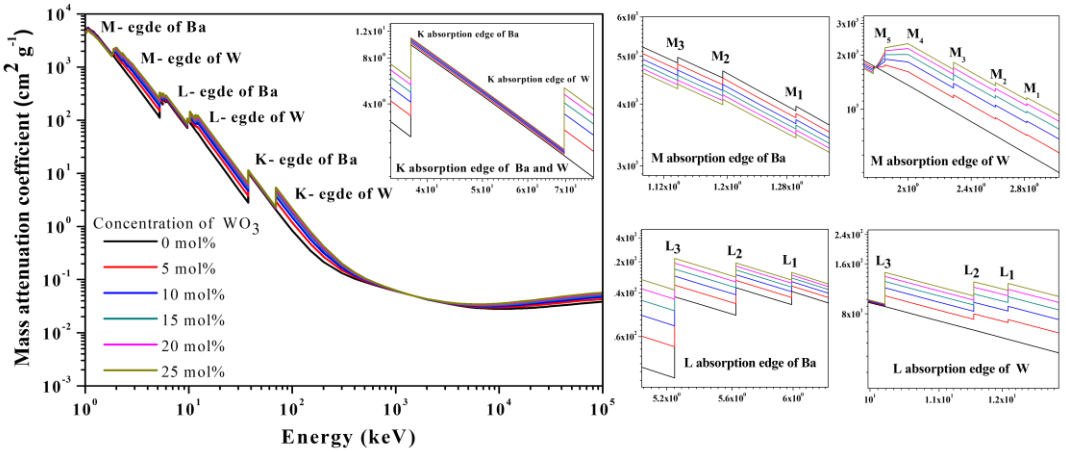

Fig. 5 The mass attenuation coefficients of WO_3:BaO:ZnO:B_2O_3 glasses

not found absorption edge of WO_3 and occur peak barium only because WO_3 are not doped in glass matrix.

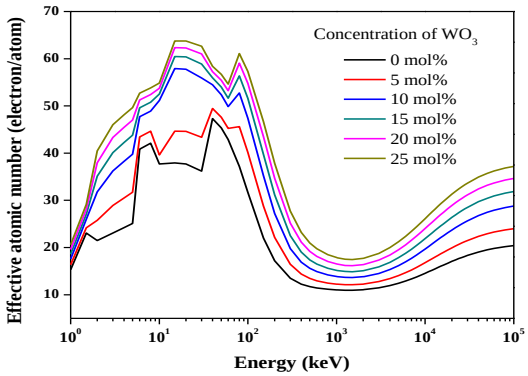

Fig. 6 The effective atomic numbers of WO_3:BaO:ZnO:B_2O_3 glasses.

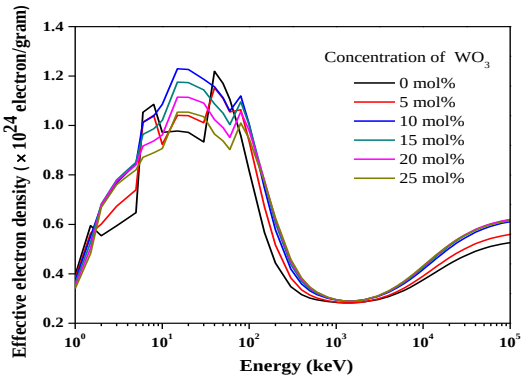

Fig. 7 The effective electron densities of WO_3:BaO:ZnO:B_2O_3 glasses.

Conclusion

The mass attenuation coefficients, The effective atomic numbers and The effective electron densities for xWO_3:20BaO:20ZnO:(60-x)B_2O_3 (where x = 0, 5, 10, 15, 20 and 25 mol%) have been investigated for total photon interaction in the energy range of $1 - 10^5$ keV by using WinXCom program. The photoelectric absorption were the main interaction at low photon energy, the values were decreased with increasing of photon energy. The values found to be the raised suddenly near the M-, L- and K-absorption edge of glass composition, and show the higher raised when increasing WO_3 concentration. Accept the blank peak not found absorption edge of WO_3 and occur peak barium only because WO_3 are not doped in glass matrix. The coherent scattering shows the values decreased with increasing of photon energy and all the trend were increased with increasing of WO_3 concentration. The incoherent scattering were the main photon interaction process and values were increased with increasing in photon energy range $1 - 10^2$ keV and decreased in photon energy range $10^2 - 10^5$ keV and all the trend were increased with increasing of WO_3 concentration. The pair production in nuclear field occurs at photon 1.02×10^3 keV and it increases with increase in photon energy and found to be the main interaction at photon energy higher 2×10^4 keV. The result of mass attenuation coefficients show the photoelectric effect is the main interaction at the low energy range, and the values show the increase with increasing WO_3 concentration in the energy range $1 - 10^5$ keV reflected to the higher to the probability interaction at higher concentration of WO_3 in this energy range and found that the blank peak of glass system occur peak of barium only due to WO_3 are not doped in glass matrix. The results of the effective atomic numbers and the effective electron densities have been appearing when the WO_3 added into this glass matrix, these have peak are corresponding to the M-, L- and K- absorption edge of tungsten and show the strong peak when increases the concentration of WO_3. These results found to be the same trend with the trend of the mass attenuation coefficients and found that the blank peak of glass system occur peak of barium only due to WO_3 are not doped in glass matrix same the blank peak in the result of the mass attenuation coefficients values.

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